Research Article

Heavy metal pollution in suburban topsoil of Nyeri, Kapsabet, Voi, Ngong and Juja towns, in Kenya

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Abstract

The increasing industrialization and agricultural developments in suburban areas of Kenya, has increased the threat of heavy metal contamination in soil. Until now, there are limited studies evaluating metal pollution in suburban towns. This study, therefore, investigated the concentration, distribution and environmental risk of lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), mercury (Hg), arsenic (As) and cadmium (Cd) in five townships. Heavy metal source apportionment was examined using principal component analysis and validated using cluster analysis. The relationship between heavy metals was analyzed using Pearson's correlation test and the ecological risk index calculated to determine the degree of contamination. The concentrations of heavy metals were 1.65–99.16, 0.2–12.50, n.d. (not detected)–2.28, 0.59–17.22, 0.18–4.93, 0.17–1.55, 0.01–0.23 and n.d.–0.03 mg kg^{-1} for Zn, Pb, As, Cu, Cr, Ni, Cd, and Hg, respectively. These values were within the toxicity limit of Tanzania soil guidelines. The results further demonstrated that natural and anthropogenic activities influenced the distribution of heavy metals. Correlation coefficients highlighted an association among heavy metals suggesting a similar origin. Pollution indices revealed that pollution decreased in the order Juja > Ngong > Kapsabet > Nyeri > Voi with the overall ecological index indicating a low level of pollution. The concentration of As and Pb were found to be high in all the study sites posing a potential hazard to the environment while Juja and Ngong regions were at a higher risk of threat. The inappropriate disposal of industrial and municipal effluents, agricultural practices, and burning of fossil fuels, was identified as the key causes of metal pollution.

Keywords Concentrations · Contamination · Ecological risk · Heavy metals · Kenya · Topsoil

Mathematics Subject Classification 62Hxx · 62H10 · 62H20 · 62H25 · 62H30

JEL Classification Q5 · Q53

1 Introduction

Environmental pollution from heavy metals is continually increasing in developing countries resulting in high concentrations of trace elements in the soil [1]. The soil pollution from heavy metals in these areas has been mainly linked to the expanding urbanization and industrialization activities [2]. In Africa, heavy metal pollution results from natural sources, including weathering of rocks and the tectonic movement of the earth. Human activities also contribute to the dissemination of pollutants in the surroundings leading to toxic pollution in major cities [3]. Some of the anthropogenic activities include; improper disposal of municipal waste, and domestic effluent, agricultural

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fertilizers, mining activities, small-scale manufacturing industries, burning of fossil fuel, and vehicular traffic emissions [4–6]. Additionally, human interference with the biogeochemical systems of the earth, lead to the enhanced release of naturally occurring heavy metals into the environment and soils act as the significant sink [7]. Over time, these heavy metals accumulate and remain in the soil medium for an extended period owing to their persistent nature [8]. Humans and animals are then exposed through inhalation, ingestion, and from direct contact with contaminated soils [9]. Plants grown on this polluted soils take up the heavy metals, and through the bio, magnification enters the food chain [10]. Moreover, a decline in plant development and yield was observed in plants grown on heavy metal contaminated soils, indicating a decrease in food production [11]. Some of the toxic heavy metals include lead (Pb), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), mercury (Hg), arsenic (As), and cadmium (Cd).

Previously, heavy metals have been documented in various environment, posing concerns to human well-being [12–15], and animal health [16, 17]. In areas with intensive industrialization activities, children are especially at a higher risk of exposure to these potentially toxic elements through soil [18]. Research on the metal pollution of suburban areas has also been done in different countries, and elevated levels of heavy metals in the soils were recorded [19–21]. The soil pollution of these cities was primarily associated with industrial and municipal effluents.

In Kenya, the suburban towns are some of the areas experiencing rapid population growth and development. However, these townships are faced with inadequate planning, which transforms into an imbalance in economic growth, and environmental sustainability is a challenge [22]. Monitoring of heavy metals in these areas is therefore crucial as their concentrations in soils affect the plants and water ecosystems, which are vital resources to livelihood [23]. Recently, the use of chemicals in manufacturing and agricultural sectors has increased, contributing to environmental contamination of natural resources and a decrease in biodiversity [24]. Moreover, the continuous utilization of pesticides in farms, lack of proper waste management systems, and the improper disposal of waste in the country raise concerns on pollutants in the environment [25]. For instance, in the suburban setting, there is rapid economic growth, coupled with the emergence of factories and industries. The problem of population upsurge and the increased use of motor vehicles have also become very rampant [3]. This upward trend in development makes townships significant areas for assessment of contamination. It is particularly important to examine the potential ecological danger and predict the contamination trend of metal elements in these soils to mitigate and establish legislative policies for environmental protection. However, no studies have focused primarily on suburban areas in Kenya hence the purpose of this study. The information obtained will, therefore, be useful toward the sustainable management and protection of the environment. This study was thus formulated to provide comprehensive data on heavy metal contamination in top suburban soils of Kenya. The concentration levels of eight significant heavy metals including, Pb, Cr, Cu, Ni, Zn, Hg, As and Cd, were determined. Heavy metal sources were assessed to ascertain the origin of the contamination. Social and environmental potential risks were evaluated by comparing the findings in this study with other studies and with the Tanzania soil quality guidelines. Moreover, the potential ecological risk index was calculated to provide ample information on the probable risk posed to the surroundings.

2 Materials and methods

2.1 Study area

Soil sampling was collected randomly from five different counties including; Thika (Kiambu County), Ngong (Kajiado County), Kapsabet (Nandi County), Voi (Taita Taveta County), and Nyeri (Nyeri County) (Fig. 1). The study areas were chosen as representatives of various parts of the country for comparison purposes. The sampling sites focused on locations influenced by anthropogenic activities from intensive farming activities through the utilization of agrochemicals. The areas are also characterized by a high population influx with rapid economic development coupled with growth in infrastructure and the rise of industries.

The first study site is Ngong town, a well-developed suburb where crop farming and livestock rearing are the main economic activities. In the area, there exists a dumpsite where tons of waste is deposited in vast acres of land. Burning of wastes and plastics are some of the significant soil pollution sources in the area. Use of animal waste and commercial fertilizers in the farms was also noted. Vegetables grown near the waste dumpsite were primarily cultivated using wastewater. The use of firewood-based stoves and charcoal for cooking was observed in the densely populated Mathare slum in the area. The second study area is Kapsabet, an agricultural town where tea and corn are grown mainly hence the utilization of agrochemicals. The region also has an open dumpsite where solid waste is disposed of haphazardly, causing severe pollution. Moreover, the open burning of wastes and the use of fossil fuel in households are frequent. The third study site is Voi, a major transport service town located along the Nairobi–Mombasa highway. Voi area is prone to high automobile fuel emissions from the heavy commercial vehicles that frequent this route. The

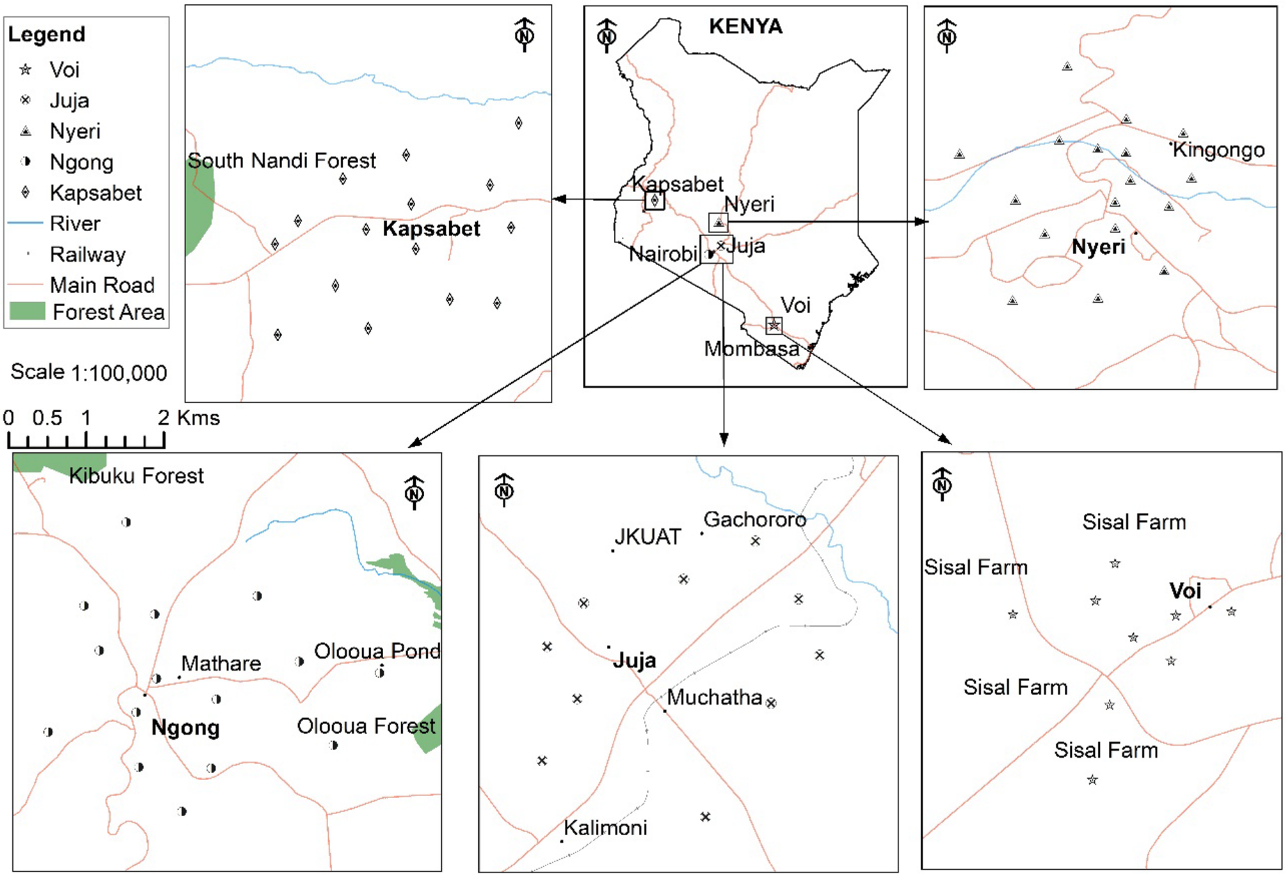

Fig. 1 Map of sampling points showing Juja, Ngong, Kapasabet, Voi, and Nyeri townships

community in the region grows sisal on a large scale, along with other food crops hence the use of pesticides and fertilizers to increase production. Household wastewater from the area is disposed of in shallow trenches resulting in pollution of soil. The fourth site is Juja Town. Juja is witnessing rapid growth with the recent construction of the Thika Highway. However, the traffic emissions in the area have increased, linked to the use of Pb gasoline fuel. Alongside the busy road, there are apartments and hotels increasing pollution from household wastewater attributable to the poor drainage in the area. Lastly, Nyeri is an agricultural town with large-scale farming of tea and coffee. Besides, both small- and large-scale farming of corn and dairy farms are also present. The area also comprises of several factories involved in coffee and tea production for export [26]. Burning of waste, including animal waste, maize cobs, coffee, and tea prunes, is frequent.

2.2 Sample collection, preparation, extraction, and analysis

Sixty-six samples were collected from different sites as follows; Juja (10), Ngong (15), Kapsabet (15), Voi (9) and, Nyeri (17). The topsoil (0–30 cm depth) was sampled using a small shovel and packed in zip lock bags. The heavy metals were extracted using a method previously reported by Mungai et al. [6]. Sample preparation involved the following steps: approximately five grams of the resultant sample was freeze-dried at high pressure, pulverized, and sifted using a 60-mesh sieve [27]. About 0.15 g of the soil sample was transferred into digestion tubes where 4 mL nitric acid and 2 mL hydrofluoric acid was added. The resultant homogenous mixture was then placed in the microwave digestion system (milestone ethos one) at regulated temperature and pressure for 2 h for decomposition to occur. The digested samples were afterward placed on a hot plate at 180 °C for solutions to vaporize. After cooling, the residues were transferred into conical flasks where double distilled water was added to the 50 mL mark and then filtered using 0.45 µm filters to remove any solid matter. The target heavy metals were then analyzed using the inductively coupled plasma -mass spectrometer (ICP-MS). The use of ICP-MS method has the advantage of high sensitivity and precision. This method allows for quantification of trace concentrations of heavy metals with accuracy at a comprehensive linear array. About 0.005 g of the sample was bounded in a tin foil and placed in the TOC Analyzer (Elementar, Inc., Germany) to examine the total organic carbon (TOC) levels in the soil.

2.3 Quality assurance and quality control

The Inductively Coupled Plasma–Mass Spectrometer machine was calibrated to assess the response factor and evaluate instrumental precision. Cross-contamination was evaluated by running a routine blank and a spiked sample containing the analytes to check for interference. The glassware used in the experiment was first soaked in (5% v/v) nitric acid and afterward cleaned thoroughly using double distilled water and finally dried in the kiln before use. All the samples were tested in triplicates for accuracy. Standard solutions for the tested heavy metals showed relative coefficients standard curves greater than 0.9933.

2.4 Risk assessment

The Hakanson potential ecological risk index (PERI) was used to determine the threat posed by heavy metals in soil. This method takes into account the set background soil standard values to analyze the potential environmental risk of the heavy metal in soil. In our study, soil background values for Kenya are not available, and hence, Tanzanian soil background values were used for reference. The pollution risk index is thus given by the overall sum of the ecological threat of a single heavy metal in the soil [28]. In this study, the heavy metal potential hazard was calculated for, As, Pb, Hg, Cd, Cr, Ni, Cu, and Zn. The formulas used to quantify the heavy metals were as follows [29].

$$C_f^i = C_{\text{surface}}^i / C_{\text{reference}}^i \tag{1}$$

The contamination factor C_f^i represents the pollution index of a single metal element which can reflect the pollution character of the investigated region but cannot reveal the ecological effects and hazards. C_{surface}^i refers to the obtained content of heavy metals in our study soils. While $C_{reference}^i$ gives the contextual set soil quality guidelines of the heavy metals. Due to the absence of soil reference standards of heavy metals in Kenya, Tanzania soil background values were used as a reference.

To determine the toxicity of a single heavy metal (E_f^i) the following formula was used;

$$E_f^i = C_f^i \times T_f^i \tag{2}$$

where T_f^i refers to the toxicity response aspect for a single heavy metal. This method typically discloses the threats posed by heavy metals on human health and the surrounding environment and reveals the metal toxicity degree and ecological sensitivity to the heavy metal pollution. The method takes into account the homogeneous response factor of heavy metals based on toxicity. The response factor values include 5, 2, 5, 1, 5, 10, 30, and 40 for Ni, Cr, Cu, Zn, Pb, As, Cd, and Hg, respectively, as specified by Hakanson [28]. The E_f^i is then calculated by the product of the contamination factor and the toxicity factor, defined as the probable risk factor for single heavy metal. To further examine the overall pollution of the different areas, the calculated E_f^i value is then analyzed using the descriptive categories defined by Hakanson [29]. Where, $E_f^i < 40$, defines low environmental risk; $40 \leq E_f^i < 80$, moderate risk; $80 \leq E_f^i < 160$, considerable risk; $E_f^i < 320$, high risk; and $E_f^i \geq 320$, very high environmental risk.

Lastly, the RI value which symbolizes the integrated single heavy metal contamination factor values is given by

$$\mathrm{RI} = \sum_f^i E_f^i \tag{3}$$

Similarly, the RI value is grouped into four grades $\mathrm{RI} < 150$, indicates minimal environmental risk; $150 \leq \mathrm{RI} < 300$, reasonable environmental risk; $300 \leq \mathrm{RI} < 600$, substantial risk; and $\mathrm{RI} \geq 600$, very high environmental risk.

2.5 Statistical analysis

The data were explored using SPSS 21.0 software, Microsoft Excel 2010, and Origin data analysis, and graphing software. All statistical variations were considered significant at the $p < 0.05$ level. The association between heavy metals and TOC was evaluated using Pearson's correlation analysis [30]. Pearson correlation test was used as a measure of linearity, and heavy metals with good association were grouped indicating a similar source of pollution. To further determine the pollution sources, principal component analysis (PCA) using varimax rotation [31, 32] was used and corroborated with hierarchical cluster analysis according to Ward's technique with Euclidean distances [33, 34]. PCA was applied to extract significant variables. The varimax rotation amplified the entities of element loadings values across the measured variables, and the varimax factors with loading components of ≥ 0.5 were considered. HCA was used for sorting of similar metal elements into clusters, where the number of groups either emanates from an anthropogenic or natural source. To assess the intensity of metals in the soil, the average, standard deviation, and range values were calculated.

3 Results

3.1 Concentration of heavy metals in soil

In the five suburban towns studied, the concentration of all the tested heavy metals is presented in Table 1. The mean values of Zn, Pb As, Cu, Cr, Ni, Cd, and Hg in the soils were 9.3 ± 12.54, 1.92 ± 2.13, 0.70 ± 0.73, 2.01 ± 2.23, 0.84 ± 0.7, 0.58 ± 0.30, 0.06 ± 0.04, and 0.01 ± 0.01 mg kg^{-1}, respectively. The overall concentration ranges of the eight heavy metals were observed to be 1.65–99.16, 0.2–12.50, n.d–2.28, 0.59–17.22, 0.18–4.93, 0.17–1.55, 0.01–0.23 and n.d.–0.03 mg kg^{-1} for Zn, Pb As, Cu, Cr, Ni, Cd, and Hg, respectively. The heavy metal concentrations fell within the set Tanzania standard values. The total organic matter in the soil ranged from 0.03 to 2.65%.

Among the tested heavy metals, the pollution by As was high in Juja compared to the other study sites with a mean of 1.59 ± 0.36 (range 1.06–2.28 mg kg^{-1}). In Ngong town, the high mean concentration of Zn and Cu was observed (Table 1). The levels of Ni and Hg were found to be relatively higher in Kapsabet than all the other studied areas. The soils from Nyeri exhibited the highest levels of Zn, Pb, Cu, Cr, and Cd. Overall, Zn showed high concentration values in the soils of all the studied areas with a mean of 9.3 ± 12.54 mg kg^{-1}. Its maximum concentration (99.16 mg kg^{-1}) was observed in Nyeri town.

3.2 Heavy metal source apportionment

Heavy metals source distribution was determined using PCA. PCA is a statistical tool that helps in grouping data according to their related patterns and identifying sources of metals in the surroundings [32]. In our study, PCA was carried out to define the source apportionment of the eight heavy metals tested for the study areas using the Varimax method (Table 2). Two principal components (PC) with eigenvalues of 3.740 and 2.278 were extracted, which explained an overall variance of 75.228%. PC1 accounted for 46.748% of the total variance with high scores of Ni, As, Cd and Hg (Fig. 2) defining the lithogenic factor. PC2

Table 2 Rotation sums of squared loading of heavy metals for principal component matrix

Component	Eigenvalues	% of Variance	Cumulative %
1	3.740	46.748	46.748
2	2.278	28.479	75.228

Extraction method: principal component analysis

Rotation method: Varimax with Kaiser normalization

Table 1 Average concentration levels, range, and standard deviation of heavy metals in suburban soils of Kenya and the standard background values of Tanzania (mg kg^{-1})

	Zn	Pb	As	Cu	Cr	Ni	Cd	Hg	TOC (%)
Juja (*n* = 10)									
Range	4.22–5.93	1.20–1.75	1.06–2.28	0.64–2.68	0.77–2.61	0.39–1.12	0.07–0.10	0.02–0.03	0.05–0.63
Mean ± SD[a]	5.12 ± 0.59	1.51 ± 0.16	1.59 ± 0.36	1.61 ± 0.68	1.43 ± 0.56	0.75 ± 0.26	0.09 ± 0.01	0.02 ± 0.00	0.24 ± 0.05
Ngong (*n* = 15)									
Range	3.64–14.54	0.73–1.31	0.35–2.13	0.99–5.35	0.26–1.87	0.32–1.21	0.05–0.11	0.01–0.02	0.07–1.29
Mean ± SD	6.28 ± 2.74	0.98 ± 0.20	1.30 ± 0.46	2.20 ± 1.17	0.83 ± 0.48	0.71 ± 0.25	0.08 ± 0.01	0.02 ± 0.00	0.34 ± 0.08
Kapsabet (*n* = 15)									
Range	3.42–35.84	0.42–7.69	n.d[b].–1.72	0.59–2.33	0.22–1.35	0.23–1.55	0.01–0.10	n.d.–0.03	0.03–1.71
Mean ± SD	10.55 ± 9.47	2.05 ± 2.07	0.67 ± 0.57	1.45 ± 0.44	0.82 ± 0.32	0.68 ± 0.40	0.05 ± 0.02	0.01 ± 0.01	0.51 ± 0.13
Voi (*n* = 9)									
Range	1.65–17.83	0.2–7.79	n.d–0.21	0.86–1.58	0.18–0.58	0.17–0.41	0.01–0.02	n.d.–0.01	0.25–1.25
Mean ± SD	6.69 ± 4.97	2.15 ± 2.93	0.10 ± 0.09	1.09 ± 0.26	0.36 ± 0.13	0.29 ± 0.09	0.01 ± 0.00	0.01 ± 0.00	0.56 ± 0.13
Nyeri (*n* = 17)									
Range	4.84–99.16	0.43–12.50	n.d–0.24	1.09–17.22	0.32–4.93	0.32–0.73	0.02–0.23	n.d–0.02	0.23–2.65
Mean ± SD	14.70 ± 22.03	2.68 ± 2.92	n.d ± 0.20	3.12 ± 4.07	0.76 ± 1.08	0.44 ± 0.12	0.05 ± 0.05	0.01 ± 0.00	0.9 ± 0.20
Overall									
Range	1.65–99.16	0.2–12.50	n.d–2.28	0.59–17.22	0.18–4.93	0.17–1.55	0.01–0.23	n.d.–0.03	0.03–2.65
Mean ± SD	9.3 ± 12.54	1.92 ± 2.13	0.70 ± 0.73	2.01 ± 2.23	0.84 ± 0.7	0.58 ± 0.30	0.06 ± 0.04	0.01 ± 0.01	
Tanzania standard values	150	200	20	200	100	100	1	2	[63]

[a] Standard deviation

[b] n.d. not detected

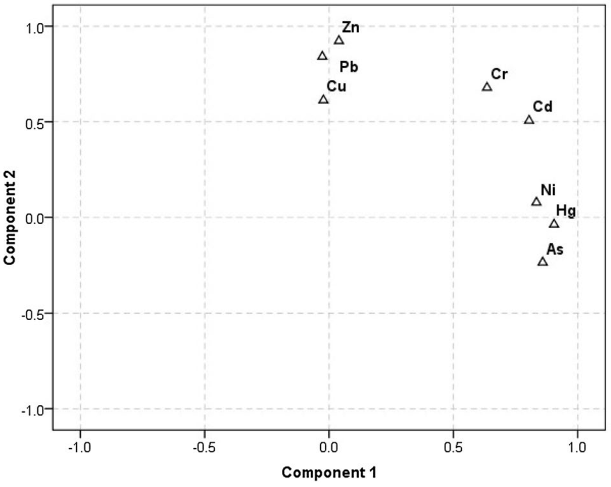

Fig. 2 Heavy metals loading scores of extracted components obtained for eight heavy metals in suburban topsoil in Kenya

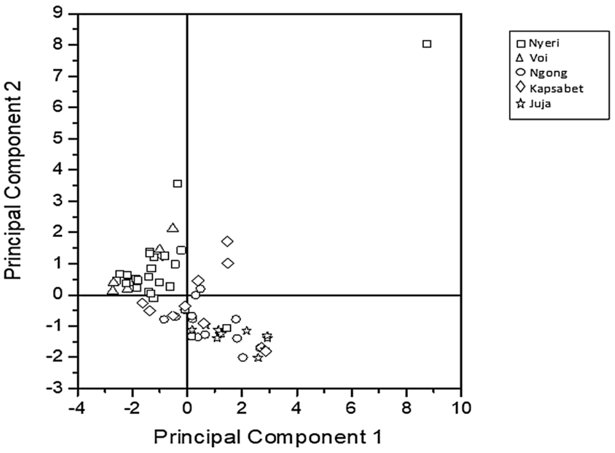

Fig. 3 Loading scores of extracted principal components in suburban topsoil in Kenya

explained 28.479% of the entire variance with an eigenvalue of 2.278. This module was highly associated with Zn, Cu, Pb, and Cr (Fig. 2) and was referred to as the anthropogenic component. Besides, it was observed that Cr showed almost equal loading values in the two derived components. Figure 3 illustrates the loading plots of PC1 and PC2 for the five towns. The sampling sites depicted high positive loading values of PC2.

For clearer observation of data, cluster test was done as a confirmation test for source identification results. Generally, the hierarchical cluster analysis sorts data into clusters based on their strong associations [34]. According to this analysis, the smaller the value on the axis, the greater the significance of the association. With reference to Fig. 4, the relationship between and among heavy metals groups derived two clusters similar to PCA results above (Fig. 2).

The first cluster comprised of Cd, Hg, Ni, and Cr and As which corresponded with PCA results indicating a lithogenic source of pollution. The second cluster consisted of As, Cu, Pb, and Zn defining the anthropogenic factor.

3.3 Correlation analysis

The correlation among the heavy metals was assessed to determine the association between heavy metals and to identify the origin of pollution in the five towns (Table 3). At the 0.01 significant level metal pairs; Ni versus Cr, Zn versus Cr, As versus Cr, Hg versus Cr, Pb versus Cr, Ni versus As, Ni versus Cd, Ni versus Hg, Cu versus Zn, Cu versus Pb, Zn versus Cd, Zn versus Pb, As versus Cd, As versus Hg, Cd versus Hg, and Cd versus Pb showed a significant positive association. The strongest association was observed between Cd versus Cr ($r^2 = 0.841$), and Pb versus Zn ($r^2 = 0.701$). Additionally, at the 0.05 significant level, two heavy metal pair elements; Cr versus Cu, Cd versus Cu showed a positive association. TOC was positively correlated with Cr and Cu at the 0.05 significant level and with Zn, Pb, and As at the 0.01 significant level.

3.4 Health implications of heavy metal contaminants in Kenya

The probable environmental risk index (RI) from metal pollution in the topsoil of municipals in Kenya was assessed. The severity of pollution in the towns decreased in the order Juja > Ngong > Kapsabet > Nyeri > Voi. The risk index value (E_f^i) for a single heavy metal reported values between 0.01 and 15.87 (Table 4). These values were less than the Hakanson's risk level ≤ 40. Nevertheless, Pb in Juja town and As in Ngong town showed higher values (Fig. 5). Correspondingly, the metal of concern in Kapsabet, and Voi was As, while Cd was significant in Nyeri. Overall the summation values of risk index (RI), in descending order were 19.17, 15.82, 8.74, 1.73, and 1.67 for Juja, Ngong, Kapsabet, Nyeri, and Voi, respectively. These values of exposure index were less than the set Hakanson's RI risk level of ≤ 150. Juja and Ngong showed high-risk values compared to Kapsabet, Nyeri, and Voi (Fig. 5).

4 Discussion

The result of heavy metal concentrations revealed the presence of pollution in the five study areas (Table 1). In comparison with the Tanzania standard values, all the heavy metal concentrations fell within the set standard limit. However, elevated concentrations of As pollution was noted in Juja town associated with metal smelting and the burning of fossil fuels [35]. Moreover, in many parts of

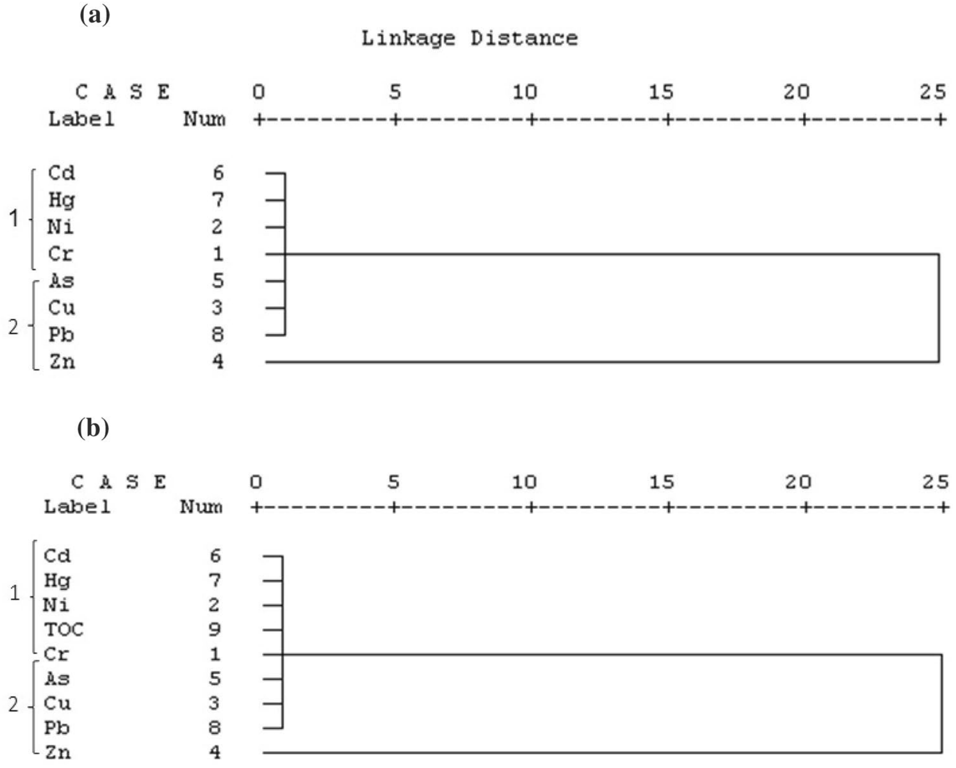

Fig. 4 The cluster analysis result of heavy metals (**a**) and heavy metals and TOC (**b**) for the suburban topsoil in Kenya using Ward's method

Table 3 Pearson correlation matrix of heavy metals and TOC for suburban soils of Kenya

	TOC	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
TOC	1	0.280*	0.005	0.243*	0.579**	−0.427**	0.172	−0.141	0.490**
Cr		1	0.583**	0.306*	0.650**	0.354**	0.841**	0.493**	0.509**
Ni			1	0.069	0.073	0.562**	0.620**	0.689**	0.034
Cu				1	0.411**	−0.074	0.271*	−0.062	0.338**
Zn					1	−0.215	0.530**	0.022	0.701**
As						1	0.599**	0.720**	−0.171
Cd							1	0.687**	0.353**
Hg								1	−0.012
Pb									1

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Table 4 Risk calculations for heavy metals in the suburban soils of Kenya

	Potential ecological risk indices of heavy metals (E_f^i)								RI
	Zn	Cu	As	Pb	Cr	Ni	Cd	Hg	
Juja	0.03	0.04	0.46	15.87	0.04	0.03	0.04	2.67	19.17
Ngong	0.04	0.06	12.98	0.02	0.02	0.04	2.33	0.33	15.82
Kapsabet	0.07	0.04	6.67	0.05	0.02	0.03	1.58	0.28	8.74
Nyeri	0.10	0.08	−0.08	0.07	0.02	0.02	1.37	0.17	1.73
Voi	0.04	0.03	1.04	0.05	0.01	0.01	0.38	0.11	1.67

Kenya, the use of wood fuel and charcoal for heating and cooking is a cheap alternative to the use of electricity and gas stove; hence, the probable source of arsenic. In Ngong town, prominent metal concentrations were linked to the toxic waste from the dumpsite in the vicinity. Studies show that waste matter from dumpsites contains toxic metal

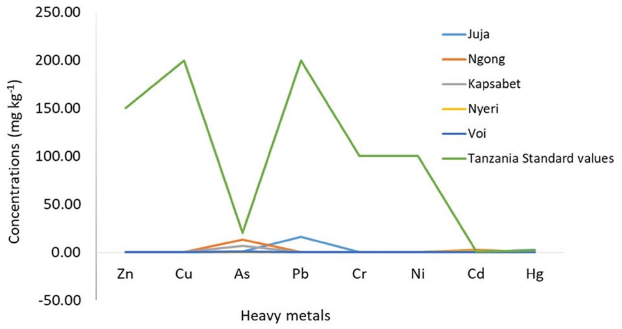

Fig. 5 Toxicity indices of heavy metals in suburban topsoil in Kenya

elements and is leached into soils leading to an upsurge of metal contamination [36]. The toxic waste from the dumpsite was, therefore, a key contributing factor to the high heavy metal pollution in the area. The use of wastewater in areas near the dumpsite was also observed. Farmers in the area are more focused on maximizing yields with less regard to environmental conservation [37]. Thus, the sustained use of wastewater in crop irrigation results in the buildup and consequently, the bioamplification of heavy metals in the food chain [38]. Tea farming activities in conjunction with the existence of tea factories in Kapsabet town were the probable sources of metal pollution in the area. Previous research indicates that the extensive application of livestock manure in farming and the improper disposal of industrial waste matter are particularly potent sources of Ni and Hg in soil [39]. Heavy metals contamination in Nyeri town was linked to industrial waste and farming activities [2]. Nyeri is renowned for its tea and coffee production with several manufacturing industries in the vicinity. Research findings further indicate that over-application of fertilizer, manure, and biosolids increase toxic metal levels in soils and plants [40, 41]. In Voi town, the heavy metal contamination was associated with farming activities at the vast sisal plantations in the area. Another significant pollution source was from traffic emissions linked to the busy Nairobi Mombasa route that, cuts across Voi town. Road transport has previously been described to be a significant source of heavy metals in soils, especially lead pollution [42].

In the five study areas, the soil contamination was associated with the improper disposal of municipal wastes, which continues to be a problem that plagues overpopulated environments in Kenya. This is mainly due to the lack of proper recycling methods in municipals and the lack of strong laws for environmental protection in Kenya. These towns also revealed the continued application of commercial fertilizer and biosolids in farms resulting in the introduction of heavy metals which leach into the soil and could potentially be biomagnified into the food chain.

In comparison with other locations, the concentrations of heavy metals in this study were found to be higher than those in Eldoret, Kenya (Zn 2.37, Pb 0.68, Cu 0.35, Cd 0.04, and Hg 0.01 mg kg^{-1}) [43]; in Samburu, Kenya Cr (2.65 mg kg^{-1}) [44]; and in Beijing (Zn 65.6, Cd 0.15 mg kg^{-1}) [45]. In contrast, the concentration of some of the heavy metals from other regions showed higher values than our study including; Samburu, Kenya (Zn 376.3, Pb 0.68, and Cd 0.04 mg kg^{-1}) [44]; Kabwe, Zambia (Zn 106, Pb 759, Cu 58.2, and Cd 22.3 mg kg^{-1}) [46]; Ibadan, Nigeria (Zn 228.6 Pb 95.1, As 3.9, Cu 46.8, Ni 20.2, and Cd 8.4 mg kg^{-1}) [47]; and in Pretoria, South Africa (Zn 67.01, Pb 62.2, Cu 88.1, Cr 34.06, and Cd 2.23 mg kg^{-1}) [48].PCA results (Fig. 2) revealed moderate concentration levels of Ni, As, Cd, and Hg in PC1 and were referred to as the lithogenic factor. The accumulation of Ni in soil was linked to the weathering of rock [49] and wind dust [50]. Arsenic pollution was linked to its occurrence in rocks, which is then released through disintegration [51]. Cadmium was linked to the fragmentation of sedimentary rocks while Hg was associated with geologic formations [52].

The second component, PC2, associated with Zn, Cu, Pb, and Cr. With reference to Table 1, Zn, Cu, Pb, and Cr also showed higher mean values in all the sites. This component was thus referred to as the anthropogenic factor. Our results also noted that Cr had equal loading scores in both components and could be released from both natural and anthropogenic sources, including the disintegration of rocks and the improper disposal of Cr containing waste matter [53]. The anthropogenic input of toxic metals in the studied regions could be from three sources. The first significant pathway is via agricultural activities. In Kenya, agronomy plays a crucial role in the provision of food for the local community and the generation of income. Both large-scale and small-scale farming are practiced in various parts of the country. For example, Kapsabet and Nyeri towns are major tea growing regions in Kenya. Likewise, in Voi town, sisal farming is done in vast acres of land, while maize farming is practiced in Juja and Ngong area. These agricultural practices may involve the use of commercial fertilizers and livestock manure, which are potential sources of soil heavy metal pollution [54–56].

Secondly, the burning of fossil fuels for cooking and improper disposal of municipal waste are some of the potential sources of heavy metal contamination. For instance, in Ngong town, there is a massive dumpsite covering several acres of land where waste is continually being deposited. Similarly, in Kapsabet town, there exists a dumpsite that poses a potential health hazard to the public. In Juja town, the lack of an efficient waste management facility results in wastes and litter routinely being dumped in open spaces. In many of these townships in Kenya, the disposal of garbage usually involves burning or discarding waste matter in public land. This process has resulted in overflowing heaps of waste matter, posing a potential health threat to the surrounding communities.

Thirdly, inadequate drainage facilities in the townships have ensued inappropriate disposition of industrial and domestic effluents. In many parts of the country, lack of a proper drainage system is still a concern [57]. Industries and residential homes are continually releasing effluents into the environment [58]. For example, in Kapsabet and Nyeri towns, tea and coffee manufacturing factories are the core industries. These industries may have an impact on the pollution of the ecosystem and consequently pose harm to human health.

PCA examination of the five sampling sites (Fig. 3) revealed that human activities had a fundamental role in the pollution of soil. In Kapsabet town, both the natural and anthropogenic factors influenced the contamination of heavy metals. Whereas, human activities showed a more significant impact, especially in Nyeri and Voi towns.

Cluster analysis test showed similar results with PCA indicating that heavy metals were derived from both lithogenic and anthropogenic sources. TOC association with the heavy metals in the first cluster indicated that the carbon content of the soil was an important factor in the availability and distribution of these metals. This is consistent with previous reports [34, 59, 60].

Pearson correlation test (Table 3) showed that there was a significant association derived among the eight heavy metals signifying similar pollution sources. Generally, the apportionment of heavy metals was attributed to several pollution sources, including human activities such as the use of crop pesticides, and the improper disposal of industrial and municipal waste and from natural sources. The correlation of TOC with heavy metals indicated that TOC played a crucial role in the adsorption and the dispersion of heavy metals in soil.

The probable environmental risk index (Table 4) indicated a low level of ecological toxicity. However, the elevated levels of Pb in Juja tend to persist in the environment posing a danger to human health [61]. Similarly, high levels of As in Ngong town poses a threat to human well-being and can be carcinogenic [62]. Correspondingly, levels of As and Cd in Kapsabet and Voi and the levels of Cd in Nyeri were of concern. This further points out that the continued accumulation and biomagnification of these elements in the food chain could threaten the health of the surrounding communities. The overall cumulative values of exposure index indicated low ecological risk. Nonetheless, the cumulative heavy metal contamination of Juja and Ngong areas posed a potential health threat to the surrounding communities compared to Kapsabet, Nyeri, and Voi.

5 Conclusion

Monitoring of heavy metal compounds in the soil provides an effective means to evaluate their concentrations and consequently compute their effect on the ecological unit. In this study, the levels of metal elements in the soils of the selected towns were found to be within the set standard values of Tanzania. When compared to heavy metals in other regions, single heavy metals in our study depicted higher concentration levels indicating a need for control measures to be implemented. Overall, Zn showed high mean concentrations in all the study sites and was predominantly influenced by human activities. The source apportionment of metal concentrations in the suburban soils further illustrated that human activities had a strong impact on heavy metal pollution in the soils. Additionally, Pearson correlation test established an inter-relationship among metal pairs indicating similar pollution origin. The incongruous disposal of waste, intensive farming practices, and combustion of fossil fuels was revealed to be the main pollution sources. The ecological risk indices disclosed that the threat posed to the surrounding environment was low. However, single heavy metals Pb and As are of particular concern and should be observed closely. Moreover, the heavy metal ecological threat of Ngong and Juja was found to be higher than the other studied areas. The findings from this study suggested the need for regular monitoring of metal pollutants in the soil, as industrialization and urbanization activities intensify. Additionally, it is necessary to implement remediation strategies to prevent the accumulation of heavy metals in the environment.

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Compliance with ethical standards

Conflict of interest The author declares that they have no conflict of interest.

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